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ABSTRACT

Current reforms in science and mathematics education call for the improvement of the quality of teaching and learning. Desired outcomes, knowledge, understanding of learning processes, and current trends in pedagogy generate a framework for an outcome-based theoretical model for science and mathematics integration. The synthesis of this selected knowledge reveals the strengths as well as the problems of such integration. In general, intuitive and practical perceptions tend to advocate the trend toward integration of science and mathematics across school curricula. Although there is little direct evidence from research to support such integration, there are no findings to strongly contradict the notion that students can benefit from integrated studies. Contains 145 references. (Author/MKR)

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TOWARD A MODEL OF SCIENCE AND MATHEMATICS INTEGRATION IN SCHOOL CURRICULUM

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Arts in the
Graduate School of The Ohio State University

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1995

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Thesis Abstract

The Ohio State University
Graduate School

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Current reforms in science and mathematics education call for the improvement of the quality of teaching and learning. Desired outcomes, knowledge, understanding of learning processes, and current trends in pedagogy generate a framework for an outcome-based theoretical model for science and mathematics integration. The synthesis of this selected knowledge reveals the strengths as well as the problems of such integration.

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CHAPTER I

INTRODUCTION

During the last two decades there has been a growing tendency to strive for change in the school curriculum for science and mathematics in the United States. There have been many developments in the fields of science and technology that require students to achieve a higher level of knowledge, understanding, and skills for everyday living, so that they can function as literate, effective members of society. School systems are beginning to recognize the need to respond to these developments.

Together with the changes in the use of science and mathematics, there have also been changes in definitions. Science has become multidisciplinary, with the boundaries between traditional subject areas practically disappearing. In most projects and research people work in teams and deal with many different subject areas. These changes are apparent even in the names of disciplines. Based on traditional disciplines, new science fields have names like biochemistry, psychobiology, physical-chemistry, etc.

Mathematics is no longer considered to be only a basic instrument for theoretical development, understanding, and communicating within scientific domains. New perspectives portray mathematics as a human-constructed science, "an experimental

science in which practitioners model 'real-world' phenomena and search for patterns in numbers, shapes, and symbols" (Anderson, et al. 1994, p. 35). According to these views, mathematical understanding is constructed by taking an active part in mathematical processes: contemplating, meaning-making, and communicating. The *Curriculum and Evaluation Standards for School Mathematics* reflect the notion of a different, new school mathematics (National Council of Teachers of Mathematics [NCTM], 1989). This new vision stresses an integration of concepts within the different areas of mathematics, e.g., algebra, geometry, analytic geometry, trigonometry, statistics, probability, discrete mathematics, calculus, topology, logic, and mathematical modeling. In addition to new developments in modern mathematics, some of them have a direct connection to scientific theories (e.g., chaos theory) and should be part of school curricula as well.

The changes in science and mathematics are relevant to education and should also influence educational strategies. The ways that science and mathematics are taught need to correspond with these new understandings and views in order to provide students with realistic views and knowledge. Changes are also apparent in attitudes toward teaching and learning. The focus has moved from curriculum and teachers to the learners (Howe, Blosser, Helgeson, & Warren, 1990). Also new trends in pedagogy start to influence curricula, e.g., cooperative learning, hands-on activities, and inquiry. "Because most change is ultimately directed at a change in student outcomes, students are a logical inclusion in the inner circle of change participants." (Anderson et al., 1994, p. 95).

In recent years, different aspects of human learning and understanding have received more attention. The focus in current research is placed on student-related cognitive aspects of learning and instruction (Gabel, 1994); on aspects of cognitive development, e.g., Piagetian theory (Malerstein, 1986; Oregon Department of Education, 1989); on patterns of misunderstanding, e.g., misconceptions (Novak, 1987); on knowledge construction - practice of constructivism (Tobin, 1993); and on the development of problem-solving and thinking skills (Halpren, 1992).

At the same time, several recent reports have released alarming facts regarding the level of science and mathematics literacy of students and citizens in the United States (Applebee, 1987; Jacobson & Doran, 1988; Mullis, Owen, & Phillips, 1990; National Commission on Excellence in Education, 1983). A large percent of the students is said to have no knowledge of basic principles and concepts of science and mathematics. Students sometimes avoid these subjects, have no motivation to learn science or mathematics related materials, and later do not choose science and mathematics related careers. Schools need to prepare all students to be part of the technology oriented modern society (Carnegie Council on Adolescent Development, 1989; Rutherford & Ahlgren, 1990). Science and mathematics should not only be pursued by an elite group of mathematicians and scientists. Thus, major adjustments are required in curriculum, both in terms of content and in teaching strategies.

A combination of science and mathematics pedagogy together with learning theories derived from cognitive psychology and from brain research should be applied in designing a curriculum that is more compatible with current knowledge of how people

acquire, use, and retain information (Krupnik-Gottlieb & Berlin, 1994). In this context, the main purpose of curriculum reform is to improve the quality of teaching and learning in order to change students' attitudes toward school science and mathematics, to increase their level of achievement, and to increase their ability to apply the knowledge they have acquired (Blosser, 1994). Integrated curriculum is promoted as a suitable way to respond to many of the current needs of curriculum reform in school education.

This work will explore the idea of integrating science and mathematics curriculum in the light of current educational reform efforts. Desired outcomes that are specified in reform documents, changes in the knowledge and understanding of learning processes, and the changing demands of the real world will serve as guidelines for this examination.

This chapter presents the general framework for the thesis. The rationale for this work is explained and the procedural details are given.

Definition of Terms

Several terms that are used throughout the thesis are defined here. The definitions are specific for this document and are not claimed to be universally accepted in the same sense elsewhere.

1. **Curriculum**: A traditional, broad definition of curriculum refers to both content and instruction. In this connotation, curriculum is referred to in the broad sense of a planned sequence of instructional units that are arranged in accordance with specific objectives and goals. This definition includes theory base, rationale, a description

of program, instructional strategies and actions, and (preferably) also a method for the evaluation of actual outcomes.

2. **Integrated curriculum**: Set of programs, actions (e.g., instructional strategies, student activities), and approaches (including theory), that are aimed at making connections among disciplines or instructional units within a curriculum. Integration would stress similarities and overlapping of "skills, themes, concepts and topics" (Fogarty, 1991, p. xiii). Integration of the curriculum can be carried out in various ways, but usually would highlight similarities and connections between the elements of the curriculum.

3. **Instruction**: Strategies and actions aimed at delivering or teaching specific subject areas to a learner or a group of learners. Instruction is defined as an active process and is included within the more general definition of curriculum.

4. **Teaching strategies**: Set of actions within a defined framework used by educators in presenting materials to students in order to improve their knowledge and process skills.

5. **Outcomes**: Set of actions, situations or facts that are the consequence of other actions or that are driven from theoretical deliberations. In association with science and mathematics education, outcomes are the results of education. Hence, *desired outcomes* are the suggested consequences of educational activity. This may include a list of expected results. *Actual outcomes* are the substantial results of specific educational actions (e.g., integration of science and mathematics) and can be measured by scientific inquiry (research results), evaluation of the action, or qualitative report.

6. **Learning theories**: An inclusive name for theories that are derived from research in the fields of neurobiology (brain research) and psychology (cognitive and developmental), that are related to learning and memory.

7. **Real-world/Real-life**: This is a notion of relevancy of school instruction to every-day life. It describes events that occur outside the school environment, but can also be part of school circumstances, and represents holistic views of processes and situations that are part of the life of average citizens.

Rationale

The value of having an integrated science and mathematics curriculum has been debated since the beginning of the century (e.g., Smith, 1905). Recently, several national commission reports call for the improvement of science and mathematics education. Among other recommendations, the notion of the integration of science and mathematics in school curriculum is mentioned (American Association for the Advancement of Science [AAAS]. Project 2061, 1989; NCTM, 1989; Rutherford & Ahlgren, 1990). Most documents recognize the relationship between science and mathematics in the real world and recommend some degree of connection in the teaching of these two subject areas. An increasing number of publications propose integration in school teaching and learning (See a comprehensive bibliography of science and mathematics integration: Berlin, 1991, 1994). However, it seems that there is much diversity in the definition of integration (Berlin, 1991). Although the number of publications that suggest integrated teaching and learning is very large, not much has

been done to present a systematic arrangement of those suggestions in terms of the objectives and the modes of integration (Berlin & White, 1994). Some forums which had set a goal to decide upon a comprehensive definition of science and mathematics integration failed to do so as they could not reach an agreement concerning the exact meaning of science and mathematics integration (e.g., *Wingspread Conference*, Berlin & White, 1992). Furthermore, most of the publications that suggest integration of science and mathematics do not include research that tests or evaluates the outcomes of integration (Berlin, 1991, 1994). From 726 publications about science and mathematics integration that were published between 1905 and April 1994 (based on the science and mathematics integration bibliographies; Berlin, 1991, 1994) and additional literature searches (conducted for the preparation of this thesis), only 9% (66) of the articles report research findings and 2% (15) of the articles include some evaluation of integrated curriculum. Theoretical and general aspects of science and mathematics integration are partially addressed in 18.5% (133) of the publications. The rest of the publications (512) describe school-based integrated activities. The literature reveals a general consensus, which is mostly based on impressions, that integration of science and mathematics curriculum is desirable and can induce better learning and understanding of science as well as mathematics.

In the development of general guidelines for a model for the integration of science and mathematics, several questions were asked:

1. What are the problems of science and mathematics education that can be addressed by an integrated curriculum?

2. What makes the integration of science and mathematics desirable based on curriculum reform? What are the characteristics of integration that provide an appropriate response to the desired outcomes for science and mathematics education?

3. What are the advantages of an integrated curriculum as far as teaching strategy, learning environment, and the learners?

4. What support exists for the notion that science and mathematics integration is a good means to reach desirable educational goals?

5. Based on the above, what would be the most desirable features of a science and mathematics integration model?

6. What are the principle issues for future research?

As explained earlier, the call for change in science and mathematics education came as a response to several problems. Some of those which are relevant to this work are: (a) continuous decline in achievement of students in science and mathematics; (b) lack of scientific literacy and mathematical competence; (c) irrelevancy of school curriculum to real-life; (d) students' failure to apply scientific and mathematical knowledge and to successfully practice problem-solving skills; and (e) negative attitudes toward science and mathematics.

An integrated curriculum is suggested as a potential response to these problems. The literature of science and mathematics integration proposes several theoretical benefits related to integration as well as some actual outcomes. In addition to what can be found in science and mathematics integration literature, more support can be based on knowledge from other disciplines. Learning theories derived from brain research and

from cognitive and developmental psychology as well as pedagogy have components that are relevant to integration and can extend the base of support for an integrated science and mathematics curriculum.

A first stage in developing a model of science and mathematics integration in school curriculum is listing the attributes of successful integration. A synthesis of theories of integration aligned with the current goals of education (desired outcomes); research results (actual outcomes) from integration literature; and theories of learning processes based on experiences from neurobiology, cognitive psychology, and pedagogy, should lead to generation of a model or a list of features needed for successful and meaningful integration.

This thesis is concerned with the synthesis described above. It is expected to reveal that some of the combined attributes from these domains provide profound support for the notion of science and mathematics integration while in other domains there is little supportive evidence, or some aspects are completely missing. For example, Berlin (1991) in her review of the science and mathematics literature found the research domain in general to be limited and incomplete. The missing domains may establish the basis for our future research agenda.

Problem Statement

The purpose of this thesis is to combine the knowledge from several domains, relevant to the integration of science and mathematics in order to outline a theoretical, outcome-based model for integrated science and mathematics curriculum. The

structuring of the desired model needs to be derived from the desired outcomes and be based on the attributes of successful integration. These attributes can be evaluated based on current research and learning theories related to science and mathematics education. Learning theories are grounded in research from the fields of neurobiology (brain research), cognitive and developmental psychology, and actual school experience. A synthesis of this selected knowledge is expected to reveal the strengths and benefits of science and mathematics integration as well as the problems and omissions that need to be reorganized and examined.

A comprehensive model for science and mathematics integration must be based on more than a sense that integration is the right thing to do in science and mathematics education. In order to address the needs of science and mathematics education, it should be outcome-based and be tested in light of current educational theories. The theoretical thought that supports integration should be confronted with the findings of educational research to determine the most effective way to implement an integrated curriculum.

Strategies

In order to identify and sort the information relevant to an integrated science and mathematics curriculum, four practical steps were followed:

1. Integrated curriculum literature (research, theory, and practice) was identified and sorted. A selection of publications from current literature and earlier years was reviewed thoroughly. Science and mathematics integration literature was drawn from the bibliography by Berlin (1991, 1994) and additional searches, as explained below. The

scanning of science and mathematics integration literature was aimed at identifying theoretical and actual (research-based) features of successful integration. Judgments of "success" are based on the reports themselves, outcomes were considered as successful if authors reported them as such. All outcomes (desired and actual) seem to be in the cognitive or affective domains. Outcomes were classified based on the current goals of science and mathematics education. Research literature was reviewed more carefully so that all aspects of actual outcomes would be recognized. Articles that describe evaluation of curriculum programs were included if they reported results that were apparently applicable to desired outcomes.

2. A review of relevant learning theories literature was conducted using the same criteria. The review focused on features of Piagetian theory, constructivism in science and mathematics, and brain processes of learning and memory. Although other areas may have some impact on science and mathematics education, these were chosen because of their greater potential for influence on current educational trends.

3. A review of relevant literature on pedagogy concentrated on theory and models of integration across disciplines. The aim was to draw from the literature on pedagogy the general characteristics of integration that are most relevant to science and mathematics integration. Several teaching strategies, e.g., cooperative work, inquiry, hands-on, usually identified with curriculum integration are also included.

4. A synthesis of the literature was done to (a) suggest a list of features that constitute the successful integration of science and mathematics in school curricula based

on desired outcomes, and (b) to provide a research agenda related to an integrated science and mathematics curriculum.

Literature review strategies and analysis

The science and mathematics integration literature review is based on several sources: 1. The bibliographies of science and mathematics integration by Berlin (1991, 1994), include articles related to science and mathematics integration from 1903 to 1994. Most of the articles were available from the special library collection in The National Center for Science Teaching and Learning (NCSTL).

2. An ERIC search located potentially relevant publications that did not appear in the Berlin bibliographies.

3. Journals that were found to publish science-math integration articles in Berlin's bibliographies were scanned (See Appendix A for a list of these journals). Only volumes of current years (1991-1994) that were not included in the bibliography by Berlin (1991) were scanned for this purpose.

4. Reference lists from all articles were checked as well, in order to find additional relevant publications.

All the articles that were identified as relevant were classified by their primary focus either as theory, research, or practice. For the purpose of this work articles that only give instructional hints or describe integrated activities (most of the articles classified under "practice") as well as articles that are related to grades other than K-12 were excluded (see "Delimitations" section). As a basis for the synthesis, all publications that

were classified as K-12 theory or research were scanned to define features relevant to science and mathematics integration including characteristics, desired outcomes, actual outcomes, suggestions, and recommendations.

Related literature from the areas of learning theories derived from brain research, from developmental and cognitive psychology, and related literature from pedagogy, was identified through ERIC and PSYCH-LIT searches as well as by scanning recent books and reference lists. Literature related to learning theories derived from brain research, psychology, and pedagogy was sorted and evaluated by the contributions to one of the following domains: (a) attributes that seem to be consistent with characteristics of science and mathematics integration as described in the literature; (b) rationale for learning theory, based on facts or perceptions (assumed and intuitive expectations); (c) relation to national goals and standards of science and mathematics (desired outcomes); (d) research and evaluation (actual outcomes) related to science and mathematics education.

Several questions guided this classification: How do the different perspectives of learning contribute to an integrated science and mathematics curriculum? What are the similarities and the contradictions between the different perspectives? What is missing and as a consequence what are the fundamental issues and research questions yet to be asked? As the issue of science and mathematics integration could not be addressed without a general definition of integration in school curriculum, another aspect that was examined was descriptions of curriculum integration.

Delimitations and Limitations

The review of the literature was aimed at describing only those features that provide an appropriate response to current science and mathematics educational goals and are expected to enhance teaching and learning in a science and mathematics integrated curriculum. This work is by no means intended to be a comprehensive review of science and mathematics integration literature, neither is it a meta analysis or content analysis. Also, the review was not done from an historical perspective nor with a comparative approach. In this work, only the aspect of *learning* is examined in relation to integration of science and mathematics. The main focus of this work is a student-related, outcome-based perspective of teaching and learning in an integrated curriculum. Although the broad definition of curriculum includes instruction as well as content, the content-related problems - the "what to integrate," is not included. Other practical problems like resources (time, money, teacher preparation), are excluded as well. The issue of integration also has an impact on teacher preparation and performance. Several programs that are aimed at preparing teachers to integrate science and mathematics in school curriculum are carried on across the United States, and more are planned (e.g., Miller, 1992; Stuessy, 1993, 1994; Underhill, Abdi, & Peters, 1994). This aspect of integration is not in the scope of this work as the literature survey is limited to K-12 integrated curriculum publications.

The effectiveness of science and mathematics integrated curriculum depends also on many factors outside the learning environment (e.g., availability of human and financial resources, collaboration, teachers availability and preparation, time management, and

school and social climate). These were eliminated from the literature survey and the synthesis in order to keep the emphasis on outcomes.

From the area of cognitive and developmental psychology, as well as from brain research and pedagogy, it is known that children differ in their perceptions, in their way of thinking, and in their abilities to learn according to their developmental level. Thus, there might be a need to apply integration models differently according to grade level. This work is limited a priori to science and mathematics integration in K-12 school curriculum. Nevertheless in an attempt to provide a general outlook of science and mathematics integration no specific age-related determinations are made. Age related, developmental aspects were contemplated only when related to an integrated science and mathematics curriculum.

Another aspect of science and mathematics integration that was excluded is the area of Microcomputer-Based Laboratories (MBL). MBL is an emerging field that is related to the integration of science and mathematics in the school curriculum. There is a considerable amount of current work that deals with aspects of MBL. Nevertheless, it was not included in this thesis. It is believed that the area of MBL instruction, which stands by itself, is too wide to be included as part of this work. It was assumed in advance that adding the aspect of MBL would expand the scope of this work beyond the desired limits and would thus disperse its focus.

In summary, the general notion underlying this work is an examination of the theoretical benefits of science and mathematics integration as generated from the synthesis of several perspectives. The outline of a model should not lead to a "cook-

book" for successful integration, neither would it generate a historical depiction or comprehensive review of integration literature. As stated earlier, this thesis is meant to identify features that are expected to be the cornerstones of successful science and mathematics integration and point out the areas to be addressed in the future.

CHAPTER II

LITERATURE BASE

In order to develop a theoretical model of science and mathematics integration in the school curriculum, based on current knowledge and expectations, a broad literature base is needed. The purpose of this chapter is to provide the appropriate background for each of the proposed elements for the model. The model is to be based on (a) expectations from an integrated curriculum as reflected in current reform efforts; (b) learning theory based on research findings about learning processes from brain research and from cognitive and developmental psychology; and (c) current knowledge and trends from the field of pedagogy, more specifically from science and mathematics education literature. The literature base provides highlights in theses areas that are relevant to the notion of science and mathematics integration in the school curriculum.

Desired and Actual Outcomes

In order to establish a successful educational program, one must define the desired outcomes first. Also it is very desirable to test the actual outcomes and compare them with the desired ones. The desired outcomes for science and mathematics education that

emerge from the theory coincide with current trends in education today. Some of the proposed outcomes are more operative than others, and some cannot be directly evaluated or tested, at least not in a short term. Nevertheless, it is important to conduct research to examine the desired outcomes. Unfortunately, in the case of science and mathematics integration in the school curriculum it seems that reports on practice are more prevalent than reports on research. The latter is limited and sometimes follows practice instead of preceding it. For example, a look through the science and mathematics bibliographies (Berlin, 1991; 1994) reveals that in 1971 and 1975 a significant number of articles dealt with integrated science and mathematics practice (49 articles compared to an average of 5 articles per year in the preceding and following years). The peak years for research articles were 1976 to 1978 with a sum of 5 articles. Since 1984, the situation seems to be better as there is a parallel increase in both research and practice reports. Nevertheless, in the last decade (1984 to April 1994), about 300 publications on science and mathematics integration practice were listed, while only about 50 publications that deal with research and field evaluation of integrated curricula were found.

Desired Outcomes at the National Level

Recognizing the fact that every part of contemporary life involves science and technology, the importance of educating students to become scientifically literate people needs to be emphasized. Schools need to prepare all students for life by enabling them to reach a certain level of scientific literacy (Blosser, 1994). The definition of scientific literacy is very broad but always includes (a) the ability to understand and use science

and mathematical knowledge; (b) the development of ways of thinking in personal or social interactions and/or everyday uses; and (c) an understanding of the connections, interactions, strengths, and weaknesses of science, mathematics, and technology (AAAS, 1993; Blosser, 1994).

In order to achieve scientific literacy students are expected to develop several abilities: (a) creative and rational thinking, (b) use of science and mathematics concepts and principles in problem-solving situations, (c) manipulation of science and mathematics materials and communication of information, (d) values and moral thinking, (e) positive attitudes toward science-mathematics-technology and its place in society, and (f) the ability for holistic thinking (AAAS, 1993; Blosser, 1994). It seems that many students in the United States, in general, do not develop those abilities, and do not reach the desired level of scientific literacy (Hamm, 1992). Therefore, in the last decade, reforms in science and mathematics education were generated at the national level.

Current educational reforms envision a radically new approach to science and mathematics instruction in the United States schools (e.g., AAAS, 1989, 1993; NCTM, 1989; National Research Council, 1990). Reforms in science education, as well as in mathematics, call for increasing connections between disciplines as an important element of those efforts (e.g., Berlin & White, 1994), but their relevancy to curriculum integration is mainly in the application to everyday experience and the development of problem-solving skills. Based on the calls for reform, it seems that both mathematics and science instruction must adjust to current needs of society by producing scientifically literate citizens who understand the place of science and mathematics in their life and are

capable of critical, analytic thinking. A common feature of reform efforts is the recognition of *constructivism* as a basis for learning theories, and the need to help students to construct a useful knowledge base. In educational terms: teach for understanding and implementation of knowledge (AAAS, 1993; Anderson et al., 1994; Carnegie Council on Adolescent Development, 1989; Howe et al., 1990; Romberg, 1993; Southwell, 1994).

The NCTM in their *Curriculum and Evaluation Standards for School Mathematics* (1989) as well as the AAAS in the *Benchmarks for Science Literacy* (1993), focus on process-oriented instruction and on teaching concepts rather than traditional disciplinary-content delivery. Their attitudes toward teaching include (a) problem-solving in a real-life context, (b) reasoning, (c) seeing patterns and relation, (d) understanding of concepts, (e) communication competence, and (f) seeing connections (Anderson et al., 1994; Hoffman & Stage, 1993). AAAS (1989, 1993) also stresses the need to teach "science for all." Schools should not be educating only the next generation of scientists, but they also need to prepare all students for life in an increasingly complex society that requires a certain level of scientific literacy from all its citizens (Rutherford & Ahlgren, 1990). A special focus is placed on the connections between science, technology, and society - STS (e.g., Bybee, 1985; Howe et al., 1990; Roth, 1992). With a need to develop mathematical as well as scientific skills, there is the recommendation to integrate these two disciplines (e.g., LaPorte & Sanders, 1993). Another common feature of both reports is their constructivist approach to learning with emphasis on "hands-on" activities and active engagement of students in inquiry versus rote learning and massive delivery

of content. Petrie (1992) describes the relevancy of the national goals to the notion of interdisciplinary curriculum as follows: "Emphasis on the tentative nature of knowledge, intellectual skills, problem-solving, the methodologies of problem-solving, reflection on the material, and one's approach to it are all very consonant with the NCTM and AAAS rhetoric" (p. 322).

Desired Outcomes from Integration Literature

Interdisciplinary programs provide a valuable tool for teachers and students. Teachers can relate to a subject as a whole and not avoid some aspects that seem to belong to another discipline (e.g., "too mathematical" for science class), and concentrate on important concepts and skills. Students are guided to connect scientific knowledge with other domains such as mathematics. For the students, ideas and materials become more clear, relevant, and meaningful, and can be viewed from multiple perspectives (Bransford & The Cognition and Technology Group at Vanderbilt, 1994; Hamm, 1992; McBride & Silverman, 1991; Stuessy, 1993).

Integration is not expected only in the content domain. Students are encouraged to integrate scientific and mathematical concepts and processes, communication skills, problem-solving strategies, critical thinking, and creativity (Neuman, 1993; Roth, 1992; Shann, 1977; Tinker, 1994). Students may be motivated more to study science and mathematics because of relevancy to their lives, and the possibilities for more different, personalized ways of constructing their knowledge (Resnick, 1983; Sanders, 1994).

From science and mathematics integration literature, it seems that expectations from an interdisciplinary curriculum are high. The integrated curriculum is perceived as a better way to increase science and mathematics literacy for *all* students (Selby, 1993). An integrated science curriculum must reflect modern content in science, mathematics, and technology, and show interdisciplinary and societal concerns. It should be a means to teach higher-order thinking, 'learning how to learn' skills, and it should refer to the uses of science and mathematics for human needs (Hurd, 1991; Sanders, 1994; Selby, 1993; Smith & Westhoff, 1992). In many instances, integration is associated with inquiry-based education, cooperative projects, and hands-on activities. The manner in which an integrated curriculum is performed influences the desired outcomes as well (Stuessy, 1993). As mentioned earlier, this work is concerned only with viewpoints relevant directly to the learners.

Student related aspects.

"The integration of mathematics and science can be highly desirable not as an end in itself but as a mean to achieve other goals" (Bransford & the Cognition and Technology Group at Vanderbilt, 1994, p.29). The main concern of the current efforts to change science and mathematics education is the students. It is apparent throughout the science and mathematics integration literature that in accordance with constructivist views, instruction is more student-oriented, i.e., teachers and curriculum are not the center, only the means to mediate knowledge acquisition. Nevertheless, "despite [the students] logical inclusion, it was not until the 1980s that research even began to look at

students as participants in their own education" (Anderson et al., 1994, p. 95). Participants of the *NSF/SSMA Wingspread Conference* (Berlin & White, 1992) listed several potential benefits for an integrated curriculum as a basis for "a rationale for its infusion into school practice" (Berlin & White, 1992, p. 341). Among them are the notion of relevancy to everyday life, a better understanding of the real world, and the cognitive and social development of the learner (Berlin & White, 1992).

Student-related outcomes are very apparent in science and mathematics integration literature. Relevant to "the learner's point of view" it is expected to achieve the following valued science and mathematics outcomes:

1. Changes in students attitudes toward science. Integrated programs provide an optimal environment to promote holistic, real-world situations, in which science and mathematics are viewed as useful and relevant (Stuessy, 1993). Future understanding may lead to acceptance. As students start to see the relevance of school subjects to their own lives, their attitudes may become more positive (Neuman, 1993). Another way to increase relevancy is adding the technological aspect. An integrated experience that may be very appealing to students would be technology-related and would include hands-on activities. This kind of work offers many opportunities to apply science and mathematics in a practical, meaningful, and motivating learning environment (LaPorte & Sanders, 1993).

An important aspect of the change in attitudes is the notion of "science (and mathematics) for all." By introducing an integrated curriculum, each student can find an interest in mathematics and science from her/his own personal point of view (Smith &

Westhoff, 1992). When students see the relevancy of school subjects to real-life they are also further motivated to learn and to use the knowledge and thinking skills they acquired at school in other scientific and every day contexts (Bray, 1969).

Fear is another component of dislike of mathematical-related subjects in school. Many students are said to suffer from mathematics anxiety and thus avoid it all together. One of the potential advantages of the integration of mathematics with science is to diminish mathematics anxiety by introducing it as the language of science and showing its use in everyday situations (Smith & Westhoff, 1992).

2. Changes in emphasis. Achievement should not continue to be measured by the amount of material memorized. The emphasis is on understanding, acquiring thinking skills, and application abilities (Anderson et al., 1994). Students are expected to acquire a level of knowledge sufficient for them to function as scientifically literate citizens, i.e., they should be able to understand the context of mathematics and science in our life, see connections, and be able to manipulate scientific and mathematical materials (Berlin & White, 1994; Hamm, 1992; Resnick, 1983; Van Haneghan, Barron, Young, Williams, Vye, & Bransford, 1992). Hamm (1992) emphasizes that for all students to achieve basic dimensions of scientific literacy it is necessary to acquire integrated knowledge (i.e., science, mathematics, and technology):

> All students should have an awareness of what the scientific endeavor is and how it relates to their culture and their lives. This means understanding the union of science, mathematics, and technology; its roots; the human contributions; and its limitations as well as its advances. (Hamm, 1992, p. 6)

3. Transfer of knowledge across disciplines and relations to real-life situations. Transfer of skills from one area to another and to real-life situations is not automatic.

Only some students have the ability to intuitively connect mathematics and science in critical thinking and in problem-solving situations (Bransford & The Cognition and Technology Group at Vanderbilt, 1994; Hamm, 1992). For the average student the connections have to be pointed out and generalizations have to be actively promoted with the teachers' guidance, in order for all students to be able to develop a personal view and be able to transfer knowledge and skills (Hamm, 1992).

An integrated curriculum provides a natural environment for "presenting mathematics and science as part of the continuing endeavor, to make sense of the universe and man's place in it" (Bray, 1969). One example is a project aimed at connecting scientific and mathematical principles to the daily news (Koenig & Kuznik, 1994). For instance, students are guided to use weather maps and sports columns, so that they can realize that math and science are part of everyday life. Another example is the rationale behind an integrated program that was developed for K-12, in New-York State (Selby, 1993). Students were expected to obtain the ability to use science, mathematics, and engineering in an inquiry-based learning environment. The aim was to make students realize that "while mathematics, science, and technology are different, each can be enhanced through the others" (Selby, 1993, p. 49), and that they should be able to manipulate them for problem-solving situations in personal and public life.

4. A change in attitudes toward science and mathematics in real-world contexts. An integrated curriculum opens up more possibilities for communications and connections with the world outside of school. The integration of science and mathematics is assumed to encourage more students to seek scientifically and mathematically related careers

(Smith & Westhoff, 1992). In an integrated curriculum, which is usually based upon current views of pedagogy, mathematics and science are presented as changing, creative disciplines that have application in the real world (Bray, 1969). On the school level, partnerships with businesses, companies, and universities is a desired component (e.g., Underhill et al. 1994).

Actual Outcomes: Research on Science and Mathematics Integration

Other than an inconclusive investigation by Gorman (1943), the intuitive assumption of enhanced learning outcomes through science and mathematics integration was not tested empirically until the 1970s. Gorman (1943) compared the effectiveness of an integrated plan of teaching 7th and 8th grade mathematics and science with the traditional approach of teaching them separately and found no significant difference in achievement between the two groups. In more recent work several aspects of science and mathematics integration were tested and evaluated:

1. Achievement and the demonstration of specific skills. Shann (1977) tested the effectiveness of a supplementary integrated program compared to a traditional elementary mathematics curriculum, for the acquisition of selected basic mathematical skills and concepts. She found that students who participated in the supplementary program (*Unified Science and Mathematics for Elementary School - USMES*) performed as well as the others, and concluded that this kind of integrated science-mathematics curriculum (USMES) did not adversely affect students' acquisition of the basic skills and concept learning (although it induced some positive attitudes toward problem-solving).

Scarborough (1993) did not find any improvement in achievement scores of high school students who participated in an instructional program that included mathematics-physics integration.

Kren and Huntsberger (1977) tested the achievement of 4th and 5th grade students after they attended science (Science A Process Approach-1) and mathematics integrated instruction. They concentrated on testing for specific mathematical skills (the measurement and the construction of angles, and the interpretation and the construction of linear graphs) to compare the groups of students attending different instructional activities for 12 days: (a) presentation of mathematics concepts prior to the related science instruction, (b) simultaneous presentation of mathematics and science concepts, or (c) presentation of mathematics concepts in science instruction before the presentation of similar concepts in mathematics. All the subjects were pretested, and then posttested 3 days after the instruction (with sections 1 and 2 of a "Kren Test"). Kren and Huntsberger (1977) found all instructional methods to be significantly effective in teaching the skills of interpretation and construction of linear graphs they tested. Mathematics and science or mathematics methods were effective to the same degree for measurement and construction of angles.

Friend (1985) investigated the effect of an integrated physics-mathematics unit on 7th graders. Achievement was tested by the *Test of Physics Facts and Principles* (Friend, 1985). Achievement scores and basic learning skills of average students were not affected by the program the students attended. Students with standardized reading and mathematics scores above grade level, who were taught by the integrated format,

demonstrated significantly greater achievement "on the Test of Physics Facts and Principles than similar students who were taught by the non-integrated format." (Friend, 1985, p. 458) Friend suggested that students in the upper level, who had the proper reading skills, benefitted the most from the integrated program as it allowed them to develop insight into physics that they would not have been able to achieve in a non-integrated format.

Goldberg & Wagreich (1991) evaluated the effectiveness of a program, *Teaching Integrated Mathematics and Science (TIMS)* that focuses on mathematics and science process skills. TIMS concentrates on the concept of a variable, and more specifically the topics of: length, area, volume, mass, and time. Pre- and posttests of 5,000 first to eighth grade students, revealed a significant improvement in mathematics and science process skills that was higher than expected. "Children gained an average of 3 years in the one year of the TIMS program " (Goldberg & Wagreich, 1991, p. 200). Proportional reasoning, which was not covered by the teaching, did not show improvement. The increase in test scores also correlated with the number of activities the student attended. Goldberg & Wagreich (1991) concluded "that a consistent amount of hands-on activities can make a real difference in student performance." (p. 204)

Acquisition of the ability to use mathematical representations as a means to communicate scientific abstract equations and to quantify concepts is one of the goals of current education (Anderson et al., 1994; Oregon Department of Education, 1990). Roth & Bowen (1994) showed that 8th grade students who experienced an integration of

science and mathematics in an inquiry-based teaching environment, increasingly used mathematical representations to support their claims in a convincing manner.

A slightly different aspect is the ability of students to manipulate science and mathematics data. One example is the use of graphs. Kren (1976) tested the ability of 4th and 5th graders to construct and interpret linear graphs as an empirical measure of the efficacy of integrated science-mathematics lessons. The assumption was that mathematical abstractions are learned better when related to meaningful experience that can be achieved by integrating mathematics with science. The results did not show a preference for integrated curriculum.

2. Students' attitudes toward integration of science and mathematics. Several studies have suggested that the integration of science and mathematics has positive effects on students' attitudes (e.g., Friend, 1985; Koballa & Bethel, 1984; Milson & Ball, 1986; Roth, 1992; Shann, 1977).

Friend (1985) tested attitudes of 7th graders toward science. The students were pre- and posttested with *The Science Attitudes Appraisal* that includes four sections: (a) scientific attitudes, (b) attitudes toward science, (c) attitudes toward scientists, and (d) enjoyment of science learning. The study compared students who took part in an integrated mathematics-physics unit to students who did not. When the different sections of The Science Attitudes Appraisal were analyzed separately, analysis of the results showed a significant increase in the "scientific attitudes" portion of the test among average students (the ones who placed at their grade level on standardized tests) in the integrated course. "Integrating science and mathematics did *not* result in a more positive

attitude toward science for students with standardized reading and mathematics scores at least *2 years above* grade level" (Friend, 1985, p. 458). These students' overall attitude scores were already high on a pre-test given before the integrated instruction took place, so there was not much room for improvement.

Shann (1977) evaluated cognitive and affective responses of elementary school students to an integrated curriculum, the *Unified Science and Mathematics for Elementary Schools (USMES)*. In the affective domain, she concentrated on the influence of USMES on students' attitudes. The attitude scale that was developed for the evaluation consisted of two parts: (a) attitudes toward mathematics and science, as well as toward strategies used in the integrated curriculum; and (b) real-life connections. Statistical analysis of a pre- and posttest showed no significant differences in overall attitudes, nevertheless the students participating in the integrated instruction express more appreciation for science.

Research outcomes are part of a report by Scarborough (1993), who evaluated a program that integrated physics, mathematics, and technology (*Phys-Ma-Tech*) in high school. It seems that "student perceptions of science changed over the course of the year" (Scarborough, 1993, p.29). Students who attended the integrated program showed a higher interest in science and a higher preference for physics.

Some other articles that describe integrated programs that include some evaluation of these programs, also report on a change in students' attitudes. Roth (1992) describes "an overwhelmingly positive attitude" toward physics classes with integrated mathematics and technological applications. Students could work on one of several different projects, connecting physics, mathematics, and technology, while the teacher spent time with any

one of them, moving from group to group. The only aspect that needed improvement, according to students' feedback reports, was related to the instructional mode and not to content. Students would prefer more individual attention during the laboratory investigations. Another example of the success of integrated courses compared with the traditional "divided disciplines" approach comes from the Soviet schools. Isayev (1993) reports on a new integrated sciences and mathematics course for Russian middle and high schools that changed the attitudes of almost all students. "Students' interest has been evident because of students' lively reactions to the lessons...even optional homework assignments are usually completed by almost all students" (Isayev, 1993, p. 52). According to Isayev, the reasons for the increased interest level and the positive attitudes were not only because of the integrated presentation but also because of the following: (a) the instruction, course books, and content were designed to appeal to the interest of the appropriate age groups; and (b) students were allowed to choose the activity, or "game", e.g., working with instruments, doing mathematical calculations, analyzing the results, being engaged in drawing graphs, or writing the reports writing.

3. Developmental aspects. Several studies relate integrated curriculum to aspects of cognitive development of the students (Almy, 1966; Ayers & Ayers, 1973; Renner, 1971; Stafford & Renner, 1976). Renner (1971) and Stafford & Renner (1976) reported a significant increase in number and length conservation abilities of young children who attended a science and mathematics integrated program. Stafford and Renner (1976) tested the influence of a science curriculum that included mathematical concepts. It seems that these experiences enhanced first grade students' ability to use conservation

reasoning. An experimental sample was drawn from three schools that used the first grade program of the *Science Curriculum Improvement Study (SCIS)*. The program focused on a direct experience of describing, grouping by properties, serial ordering, and generalizations and predictions skills. The pre- and posttests that were administered to both groups included six conservation tasks. Pre-test showed some advantage for the control group, but on the posttest the experimental group outscored the control group on every task except area.

Science experience is assumed to help the child move from concrete to operational thought, a quality that is important for both mathematics and science understanding (Ayers & Ayers 1973; Stanford & Renner, 1976). Administration of *Science: a Process Approach (SAPA)* seemed to accelerate the achievement of conservation skills of an experimental group of kindergarten children in comparison to a control group who attended a traditional program that emphasized nature studies (Ayers & Ayers, 1973). Kindergarten students were tested on six tasks: number, liquid amount, solid amount, length, weight, and area. A significant difference in favor of the experimental group was found for the total posttest score. Almy (1966) also showed that elementary school students who attended combined mathematics-science programs performed better on the conservation and transitivity tasks than did those who received only mathematics instruction. Krajcik and Haney (1987), while examining proportional reasoning and achievement in high-school chemistry students, suggested that the ability to apply proportional reasoning was a major factor that differentiated performance of students according to their Piagetian developmental level.

In summary, the limited research on integrated science and mathematics curriculum provides some support for an interdisciplinary curriculum. Integration seems to have positive effects on students' attitudes toward science. Although integrated programs do not seem, in most cases, to influence students' achievement, in some cases a positive effect was reported, e.g., for above grade level students (Friend, 1985) and for students who attended the TIMS program (Goldberg & Wagreich, 1991). It remains unclear whether the primary influence is due to the implementation of current pedagogical trends or to the integration itself. It is nevertheless suggested that students achieve as well in integrated instruction, may develop a better understanding of the relevance of science and mathematics, and thus become more aware of the relationships and connections between subject areas.

Learning Theories

The learning theories include all aspects of learning research. Brain research and relevant attributes of cognitive psychology influence current learning theories. Some aspects of learning theories have direct implications for education and are related to several elements of pedagogy.

A review of brain processes that are relevant to current educational trends has appeared elsewhere. The information presented in the following sections, related to brain research, is a compilation and rearrangement of several versions of an unpublished article by Krupnik-Gottlieb and Berlin (1994).

Brain Related Processes and Learning

Current knowledge of brain functioning is limited. Nevertheless, there are a number of models in psychology and brain research that deal with learning and memory (for a review, see Anderson, 1992). There is sufficient information on human cognition from the fields of anatomy, biochemistry, neurobiology, neuropsychology, and psychobiology to proffer a general view of brain functioning (Dudai, 1989; Fischbach, 1992; Gormezano & Wasserman, 1992; Martinez & Kesner, 1991) that can provide educational insight and a rationale for an integrated curriculum. While trying to facilitate true, meaningful learning, one should remember that the human brain is the site where most learning occurs (Caine & Caine, 1991a, 1991b). Thus, for successful teaching, the ways in which concepts are assimilated into the learner's cognitive structure, and the ways to facilitate the biological process for the learner must be considered. An integrated curriculum may be a viable approach for teaching science and mathematics if brain functions are taken into account. In recent years, Novak (1993) and others (e.g., Anderson, 1992) have tried to link neurobiological theories of human learning, knowledge on brain functioning, and constructivist models of learning. They have demonstrated that models of learning and memory processes are in accordance with the need for organized "constructed" acquisition of meaningful knowledge.

Caine and Caine (1991b) suggest going one step further by connecting findings from brain research and psychology directly to instruction. They claim that educational methodology should be based on what is known about how the brain learns and uses information, as well as other influencing attributes (e.g., emotions, nutrition) in order to promote understanding. In their book, they show that integrated instruction correlates with the way the brain operates:

> "The brain searches for common patterns and connections...Every experience actually contains within it the seeds of many, and possibly all, disciplines...One of the keys to understanding is what is technically called redundancy." (Caine & Caine, 1991b, pp. 119-120)

From neurophysiology and anatomy, it is known that the working brain is a network of neurons and synapses arranged in hierarchial layers. Inputs and outputs connect each group of neurons to almost any other group (Rumelhart & McClelland, 1986). These connections change as a result of the input or experience--a quality that has been called *brain plasticity* (Diamond, 1988; Peterson, 1984).

An aspect of brain research-based models of learning that is relevant to the notion of integrated curriculum is the parallel processing of information (Grossberg, 1984; McClelland & Rumelhart, 1985). It appears that learning that includes repetition of material from several different aspects that are routinely connected is superior to the learning of isolated, discrete events. Simultaneous inputs would generate connections within the brain and would enable a coupled response in subsequent situations. In general, the brain is

perceived as *a parallel processor* as it can handle simultaneous, multimodal input and have many internal functions activated and interconnected at the same time (Hinton & Anderson, 1981; McClelland & Rumelhart, 1985). The *interconnections* between functions can facilitate or inhibit, support or contradict each other.

Several models describe brain functioning in learning and memory as a dynamic process. The flow of information begins at the point of reception through one or more perceptual modalities (e.g., visual, auditory, olfactory, and tactile). The input stimuli whether sequential or parallel in nature, are stored initially in *Short Term Memory* (STM). A filtering system, *Working Memory* (WM), further processes the information for potential storage in *Long Term Memory* (LTM) and for assimilation into one's cognitive structure (Anderson, 1992; Kesner & Hopkins, 1992; Letteri, 1991; Squire, 1986). Although researchers still remain uncertain exactly how memory systems operate within the human brain, it is acknowledged that memory storage can be operationally defined by these three components:

1. *STM* is often characterized as immediate memory that can hold only sensory information for a very short time and has limited capacity.
2. *WM* is the "mediator" that maintains the STM activation and storage of symbolic information as well as enabling the use of that information through access to *LTM* for retrieval of connected information. WM underlies reason, language comprehension, and computational operations (Goldman-Rakic, 1992).
3. The information that is not rejected is then stored in *LTM*. This involves the development of stable changes in biochemical and neural (synaptic connections) structures in the brain. The results of these processes are sometimes viewed as assemblies of neurons that represent "chunks" of stored information or "mental images" (Squire, 1986).

The establishment of links between the implications of recent brain research and education trends promises to enable educators to apply emerging knowledge about learning directly to the educational process. It seems that many neurobiological terms are synonymous or at least harmonious with those used by educators. It is, however, interesting to note differences in definitions. For biologists and psychologists "learning" refers to the active process of acquiring information and "memory" is the outcome that can be directly tested and observed (e.g., by behavioral tests and biochemical and neural traces of memory). Spear and Riccio (1994) define memory as "the representation of all that has been acquired about a...set of events that are somehow related." (p. 3). For educators "memory" is the process while "learning" and understanding are considered the outcomes that can be tested more easily.

Elements of Brain Processes Relevant to Education

Attention is a first condition for the reception of input stimuli. Focused attention can be achieved by presenting the learner with meaningful, relevant stimuli (Naatanen, 1992; Picton, Campbell, Baribeau-Braun, & Proulx, 1978)

in a non-stressed, pleasant environment (Caine & Caine, 1991b). Stimuli can be either presented in sequential order or at the same time (parallel stimulation). The senses are capable of receiving stimuli in both ways and all stimuli are in fact recorded through the neural systems at the same time.

Multimodal input is initially processed and stored in the specialized areas of the cortex. As relationships among multimodal input are developed to create cortical fields, more stable, mutually supportive *neural networks* are created (Anderson, 1992). The neural systems that mediate learning and memory mostly store information related to the associations among stimuli rather then stimuli themselves (Kandel & Hawkins, 1992). Increased input via a greater number of channels activates more neurons. If all these neurons are activated simultaneously, the memory trace is stronger. Thus, the more details of a multimodal stimulus that are processed at the same time, the better the chances that they be stored in long term memory (stability) and the greater the possibilities for recall as connections to other stimuli (accessibility of the information).

In order for new stimuli to be connected to previously stored information, the mechanism of retrieval has to be activated concurrent with the memorization process. *Retrieval from memory* is an important element of both feedback to working memory and actions or responses. Retrieval depends on storage structure. With reactivation, the varied sensations and set of actions associated with a particular entity or category of entities can be "re-created" in order to lead to performance or to support new information for processing in memory (Domasio & Domasio, 1992). Thus, the ability to retrieve a whole concept in the appropriate context depends on the way in which the input was initially embedded and its relationship to subsequent contexts. The procedure by which one stimulus serves as a cue that activates a "string" of stored information is known in the neurophysiological literature as *priming* (Squire, 1986).

The complex neuro-anatomical structure of the brain is indicative of the complexity of cognitive processing. It is apparent that memorization (the learning process) is not a single entity and that it can take at least two forms: *Explicit learning* and memory that lead to declarative or conceptual knowledge (the "what") and *implicit learning* and memory, connected to procedural knowledge (the "how") (Kandel & Hawkins, 1992; Squire, 1986).

1. *Explicit learning*, as defined by neurobiologists, is the process that records associated stimuli, such as information about an event in a particular time and place, and also involves awareness of previous events. Explicit learning is often most successful when associated events occur simultaneously (Kandel & Hawkins, 1992; Goldman-Rakic, 1992). Explicit learning involves the temporal lobe and is more complex and thus entails more connections to neural networks that code internal representations (Dudai, 1989; Kandel & Hawkins, 1992).

2. The neurobiological definition of *Implicit learning* refers to a process that often involves connections among sequential stimuli. The stimuli activate

particular sensory and motor systems associated with the learning task by creating the connections between neurons. Repetition enhances these connections.

Both systems store information about the association of stimuli as long as the subject can still find familiar environmental stimuli associated with certain consequences and expectations. "Brain research establishes and confirms that multiple complex and concrete experiences are essential for meaningful learning and teaching" (Caine & Caine, 1991b, p. 5). Information is processed in "clusters," i.e., *connections* are made, and patterns are sought and best perceived to create "mental images" stored in memory.

In summary, some of these characteristics are more relevant for the establishment of an integrated curriculum: (a) the neural systems mostly store information related to the associations among stimuli rather then the stimuli themselves; (b) the notion of priming as a process that initiates retrieval from memory; (c) the fact that the brain better assimilates information that is connected to prior knowledge. An integrated curriculum can be most suitable for presenting information to the learner in a manner that will encourage the creation of mental patterns--understanding and applicable memorization (Caine & Caine, 1991a). Data presented as details of a whole idea or subject will be learned more effectively than if they are presented as separate, unrelated content sections. New information will be processed better if it is connected to information already stored in memory. Therefore, meaningful learning and the assimilation of new information into cognitive structure should be achieved by teaching through life-like experiences that offer relevant whole images of the information. (Krupnik-Gottlieb & Berlin, 1994, pp. 1-10)

Cognitive Theories Relevant to Education

Knowledge from brain research is still incomplete and is insufficient to explain all learning processes. Additional support for an integrated curriculum can be derived from cognitive psychology. Psychological models of learning have direct implications for teaching and curriculum design and can provide guidance in the development of a model for science and mathematics integration.

Developmental aspects of learning (Piaget).

Beginning in the early 1920s, Jean Piaget developed a cognitive theory, now known as the *Piagetian Stage Theory* (Malerstein, 1986; Piaget, 1929; 1985). According to Piaget, young children are fundamentally different kinds of thinkers and learners than adults. Stage theory assumes several general reorganizations of the child's conceptual mechanism: a shift from tangible to representational thought, from pre-logical to early concrete logical thought, and finally to the formal thinking of adults (Oregon Department of Education, 1989; Piaget, 1929; 1985).

Piaget's concern was to describe the process by which people gain knowledge about the world (Malerstein, 1986). He viewed intellectual growth as coming to know reality more objectively through developing more external, less self-focused, perceptions of reality (O'Loughlin, 1992). Piaget suggested that the individuals' interpretive schemata evolve as a result of successively more complex interactions with the world throughout their lifetime (Malerstein, 1986).

Children begin by acquiring operations that permit them to act on their world and eventually to enter the stage of formal operations and obtain abstract, logico-mathematical reasoning capacities (Piaget, 1985). Intellectual adjustment was viewed by Piaget as part of the process by which organisms engage in biological adaptation to the environment in terms of the dialectical balance between processes of assimilation and accommodation. He saw assimilation in its biological context as the integration of new stimuli into existing structures within an individual (Piaget, 1985).

Piaget maintained that progression from one level of cognitive development to another is influenced by four factors: maturation, physical experience, social experience, and "equilibration." The latter is a process by which the mind absorbs new information and "balances" new ideas with previously acquired information (Loomis & Prickett, 1985). The organism constantly tries to gain equilibrium by reducing conflict. The end result is a progressively developed ability to come to view knowledge objectively.

Social experience refers to the idea that cognitive growth is enhanced by interactions with others. Cognitive disequilibrium is stimulated by problem-solving activities in cooperative groups. Learning in such cooperative groups can be a rich environment for meaning-making (Wheatley, 1991) and can help students progress to a subsequent developmental stage.

One of the problems of Piaget's stage theory is that he viewed the differences between young children and adults as domain-independent. The child's difficulties in learning new information were explained with certain formal properties irrespective of the domain of knowledge from which the information is derived. Many developmental psychologists now believe that this interpretation is misleading and that certain phenomena described by Piaget can be better explained by presuming that children do not think differently compared to adults. The difference is that they experience theory changes merely in specific domains (e.g., Carey, 1985). Novak (1977) has tested the notion of Piagetian-based developmental stages in science education. He claims that stages refer to divergence in behavior: The increase of formal thinkers in the population is gradual and not stepped as would be expected by Piagetians. He has shown that the

type of thought demonstrated by children as well as adults depends on the context and life experience rather than on their period of development.

The Piagetian theory and constructivism.

Because the strategies Piaget studied are concerned with the abilities to interpret the natural world and to cope with abstract representations of it, his theory is highly relevant to learning in science and mathematics. Piaget's theory (1929, 1985) explains the development of logical thinking of children as it is reflected in the formation of scientific notions and mathematical understandings (as well as other areas). Constructivism is a derivative of Piaget's theory that views the acquisition of knowledge as a life-long, active, constructivist process in which individuals restructure their experiences in light of existing mental schemes (Oregon Department of Education, 1989).

The notion that learners are very individual, active, and constructive thinkers has been formally labeled as *constructivism* (Bonder, 1986). The mind assimilates input from the outside world into its own structures. The cognitive formations and processing strategies available to the learners when presented with new material lead them to select from the input what is meaningful to them and to represent and transform what is selected in accordance with their cognitive structures (Flavell, 1992).

In recent years, there has been a tendency in science and mathematics education to adopt a constructivist approach to teaching and learning (Anderson et al., 1994). A major problem confronting science and mathematics educators is to develop curricula that enable students to examine their own conceptions during learning and to construct their

own intrinsic knowledge structures (Oregon Department of Education, 1989). Combining mathematics skills and science processes in a single investigation creates a continuum of experience, practice, and application in a way that enhances the construction of meaningful knowledge for the student (Wheatley, 1991).

Constructivism and instruction.

The constructivist perspective holds that meaningful learning or understanding is constructed in the internal world of the learner as a result of sensory experiences. The learner's internal schemata can change as a result of disequilibrating experiences (Saunders, 1992). For educators, constructivism entails the notion that learners actively construct their own interpretation of events and respond to their sensory experiences by building or constructing in their minds cognitive structures (schemata) which constitute the meaning and understanding of their world (Anderson et al., 1994; Tobin, 1993). That is, it is not possible to transfer ideas and knowledge into students' heads. They must construct their own meanings by active engagement in the learning process (Wheatley, 1991). The implications for classroom instruction are consistent with the essence of science learning: the process of meaning acquisition involves a cognitive restructuring as the individual's internal world becomes more consistent with the empirical data about the external world.

In developing stage theory, Piaget collected a large amount of data concerning misconceptions of young children. Because Piaget interpreted these misconceptions in terms of 'the child's changing theories', his work has been the basis for a significant

body of research (e.g., Novak, 1987). Novak claims that reconciling new meanings with old ones (i.e., the regularities that are already known to the learner) can alter misconceptions. He shows that while teaching with meaning enhances the learner's knowledge, rote learning is more likely to dissolve and will never be integrated into a cognitive structure. Misconceptions can also appear in children's understanding of mathematical concepts (Baroody & Ginsburg, 1990). It appears that "patterns of misunderstanding," especially in novices, exhibit many similarities between situations of mathematical and scientific problem-solving (Perkins & Simmons, 1988). For example, students tend to attend to surface characteristics of problems or try to apply a more familiar procedure to simplify a solution (Stavy & Tirosh, 1992; Van Hangehan et al., 1992). An integrated approach can help prevent misunderstandings in the problem-solving level by guiding students to apply relevant knowledge and procedures.

From a constructivist perspective, learners construct knowledge and meanings according to their initial cognitive level (Driver & Oldham, 1986). Many learners, however, may need assistance in accessing and interpreting new information that is relevant to the experience, so that appropriate modifications to their schemata and links between them can be made (Appleton, 1993). Educators should be aware of "where a child is" in terms of the cognitive structure and developmental level, and "where he comes from" in terms of naive ideas and misconceptions. The role of the teacher is therefore to see that the information is presented effectively and appropriately to the learner. Teachers are not the transmitters of knowledge and skills, but rather mediators

between the body of knowledge and the learners who bring them together in a way that is meaningful for the learner (Cobern, 1991).

Resnick (1983), summarizes the fundamental view of the "Constructivist Learners":

> First, learners construct understanding. ... Learners look for meaning and will try to find regularity and order in the events of the world, ... Secondly, to understand something is to know relationships. Human knowledge is stored in clusters and organized into schemata that people use both to interpret familiar situations and to reason about new ones. (pp. 477-478)

To enhance the process of education through a constructivist approach, Kamii (1980) proposed nine teaching principles. Among them is a principle calling for the integration of all aspects of knowledge: Knowledge is developed as a whole and should not be divided rigorously into discrete subject areas. The real world is made and operates as a whole with interrelations between all disciplines.

Ausubel (1960, 1962) emphasized the importance of systematically (organized) guided exposition in the process guiding the learner to construct knowledge. To understand new information is to relate it to, and integrate it with, already existing knowledge. It is the continuity between the learner's existing cognitive structure and the new material that makes the latter meaningful and causes it to be assimilated. If the information can be meaningfully organized by the instructor, the learning process is far more efficient. Based on these principles, Ausubel's theory is sometimes referred to as the *Theory of Meaningful Learning*.

An integrated curriculum can be most suitable for presenting information to the learner in a manner that encourages the creation of mental patterns based on understanding and thus "meaningful learning." Integration can be viewed from the

perspective of the learner and how the learner's cognitive schema processes and organizes scientific and mathematical concepts, processes, skills, and attitudes.

Constructivism in science and mathematics education.

Osborn and Wittrock (1983) have related the Piagetian constructivist approach to learning science, stressing the importance of what learners bring with them to the learning situation and the active contribution of meaning derived from their interaction with the environment. Learning scientific ideas involves conceptual changes. Teaching science according to constructivist views entails providing students with a context that allows them to frame their own questions to answer through subsequent investigations. In the process of this inquiry, students are encouraged to construct new conceptual frameworks, and are assisted to acquire new practical and analytical skills (Roth, 1994). In addition educators should be attentive to learners' immaturities (Stendler, 1962) and instructional materials should be developmentally appropriate:

> During constructivist learning, students have the opportunity to verbalize, test, modify, and even abandon their pre-existing ideas and adopt new ones. Through learning tasks keyed to their developmental levels, students have the chance to make sense of the world by actively constructing meaning out of natural phenomena and their everyday experiences. (Loucks-Horsley, Kapitan, Carlson, Kuerbis, Clark, Melle, Sachse, & Walton, 1990, p.47)

Mathematics educators stress the idea that learning mathematics requires that the learner take an active role. In order to know and understand mathematical concepts, students need to be engaged in constructive work in a mathematical environment: hypothesizing and executing mathematical procedures individually as well as communicating results and collectively reflecting on methods and mathematical

procedures (Daniels, 1993; Davis, Maher & Noddings, 1990). In recent years, the idea of constructivism has become widely accepted in the community of mathematics educators, although there are still debates among theoreticians concerning the essence and dispositions of constructivism.

By traditional constructivism it is assumed that children are continuously engaged in constructive activity to generate their individual understanding (Noddings, 1990). Without proper guidance, this process sometimes leads to the generation of "weak constructions" or misconceptions (Confrey, 1990). To help educators to promote the development of true understanding, Confrey lists the qualities necessary for a body of knowledge to be constructed properly by the students. Among these qualities are: (a) internal consistency; (b) "an integration across a variety of concepts; (c) a convergence among multiple forms and contexts of representation; [and] (d) an ability to be reflected on and described" (Confrey 1990, p.111). These qualities can be achieved by integrating school mathematics with science in a real-world context.

By contrast to traditional constructivism, which refers only to the view of learning as being built on prior knowledge, von Glaserfeld (1990) argues that knowledge cannot be separated from the process of knowing. The only reality is what is constructed within the learner. His theory is known as *Radical Constructivism* (Tobin, 1993; von Glaserfeld, 1990). Radical constructivists "assert that there are only intersubjective meanings for the experiences that individuals share" (Anderson et al., 1994, p. 39). Reality is subjectively constructed within the learner. Hence, there is no "true knowledge" that can be transferred from teacher to student; knowledge cannot be

communicated but can only be constructed by the individual (von Glaserfeld, 1990). This generates a problem of the implications of constructivism for science and mathematics education.

Despite theoretical debate, constructivism is widely recommended as a basis for science and mathematics instruction as apparent in the NCTM standards (NCTM, 1989) and current developments of science education curriculum (e.g., AAAS, 1993; Oregon Department of Education, 1989). Davis et al., (1990) summarize the application of constructivists theory to mathematics education:

> Constructivists agree that mathematical learning involves the active manipulation of meanings, not just numbers and formulas. They reject the notion that mathematics is learned in a cumulative, linear fashion. Every stage of learning involves a search for meaning, and acquisition of rote skills in no way ensures that learners will be able to use these skills intelligently in mathematical settings. Misconceptions may develop anywhere in the process, and constructivist teachers are continually watching for them and planning activities that will lead students to challenge their own faulty conceptions. Constructivists recommend providing learning environments in which students can acquire basic concepts, algorithmic skills, heuristic processes, and habits of cooperation and reflection. (p. 187)

Interdisciplinary approaches coincide with constructivist theories in several ways. The most prominent ones are encouraging flexibility of thought and allowing students to "personalize" their learning by weaving together ideas from different curricular domains and examining them from different perspectives.

Pedagogy

Characteristics of Integration

The calls for integrated curriculum are inspired by current movements that call for the increased relevance of education in school for real life (Jacobs, 1989). Integrated

curriculum is based on the notion that ideas and concepts should cross traditional boundaries between subject matters as they do in the real-world. In fact, for most scientific applications in the real world these boundaries no longer exist (Howe et al., 1990). It is apparent in the new definitions of science fields (e.g., neuropsychology, biochemistry, sociobiology, biophysics, and physical chemistry) which represent combinations of traditional disciplines in a single term. At the same time, solving real-life problems demands team work and collaboration between specialists; one person is not necessarily able to conceptualize such broad domains in an adequately profound manner. Hence, integration of school curriculum is aimed at helping students to realize and be prepared for the need for cooperative work in real-life situations (Stuessy, 1993) and to see the natural linkage between disciplines. In a traditional teaching approach, students receive information within the distinct discipline and an integration is expected to occur, if and when needed, in the individual's mind (Petrie, 1992; Stevenson & Carr, 1993). Integrated curriculum is aimed at providing a holistic view of "the world" and emphasizes the various interconnections among disciplines as well as common features, concepts, and skills (Bransford & The Cognition and Technology Group at Vanderbilt, 1994). The interdisciplinary or integrated approach is less concerned about content and more concerned with practical aspects of knowledge acquisition and problem-solving (Petrie, 1992).

A further point of view that leads to recommending integrated curriculum comes from the cognitive sciences. In this context, Caine & Caine (1991b) stressed the fact that the brain, the site where learning occurs, searches for patterns and interconnections in

order to generate meaningful learning and memory. When meaningful learning is desired, connections among and within disciplines should be stressed (Drake, 1993), and should be organized in a holistic, interdisciplinary manner (Caine & Caine, 1991b). It is also suggested that integrated curriculum facilitates the transfer of knowledge across disciplines and enables students to use common skills and problem-solving strategies (Bransford & The Cognition and Technology Group at Vanderbilt, 1994; Drake, 1993; Jacobs, 1989).

Several publications are aimed at helping the transition from theory to practice in order to encourage educators in developing integrated programs (Drake, 1993, Fogarty, 1991; Jacobs, 1989; Klein, 1990; Lounsbury, 1992; Stevenson and Carr, 1993; Vars, 1987). Fogarty (1991) presents a graphic demonstration of ten simplified integration models in order to help educators in integrating the curriculum. Some of these models seem to be more applicable to the integration of mathematics and science:

1. The *nested* approach: The teacher targets multiple skills within a subject area. This is probably the most common way of integrating mathematics in science class. For example, using calculations while teaching chemistry by graphing the results of calculated percentages of substances that undergo chemical reactions.

2. The *sequenced* approach: Topics or units are rearranged and sequenced to correlate so that similar ideas are taught at the same time while the subjects remain separate. For example, a unit in physics on electricity is taught at the same time as calculus and is followed by a unit in biology about the nervous system.

3. The *shared* curriculum: This is a very demanding method. Science and mathematics teachers have to work together to use data collection, charting, and graphing as shared concepts that can be team-taught.

4. *Threaded* integration: A common skill, concept or way of thinking would be targeted by science and mathematics teachers, each in her/his own content area. An example is threading "prediction" in mathematics problem-solving as well as in science lab experiments.

5. *Webbing* the curriculum: A broad topic or concept is used as a central subject to work within the different subject areas or disciplines. The webbing process may be used to sketch out an interdisciplinary unit. This process is especially useful in smaller schools and in those without restrictive curriculum guidelines, where it is possible for teachers to concentrate on specific themes rather than on content.

6. *Integrated* teaching: A teaching approach which matches overlapping topics and concepts from different disciplines. Teachers of these disciplines work together to coordinate their teaching. The aim is to approach content, which includes information from several traditional disciplines through the same patterns, to use the same language, and to emphasize the same concepts, processes, and problem-solving skills.

There is no single approach to curriculum integration. "Teachers should be active curriculum designers and determine the nature and degree of integration and the scope and sequence of study" (Jacobs, 1989, p. 9). The common belief is that integrated teaching enables students to perceive a more holistic picture of reality (e.g., Fogarty, 1991). But it is clear that an integrated curriculum needs to be carefully designed to

avoid chaos and to enable students to acquire a solid grounding in at least portions of the specific disciplines before the integration of their components (Gardner & Boix-Mansilla, 1994; Jacobs, 1989).

Science and Mathematics Integration

The natural and essential relationships between science and mathematics make these subjects most appropriate candidates for integration. Mathematics is not only an application instrument for scientific inquiry. Mathematics and science are both fields that share methods of inquiry and a need for higher order thinking skills (e.g., McBride & Silverman, 1991). Inquiry-based science teaching, with hands-on investigation, is virtually impossible without using mathematical language for measurement, number relationships, and symbols (Aghadiuno, 1992). In school practice, mathematics helps clarify science, contributes accuracy to measurements, and influences problem-solving in science. Science in turn provides mathematics with realistic problems that enable students to observe and apply mathematical procedures and patterns (Neuman, 1993). The connection is also apparent from a historical perspective. The field of mathematics has developed in all ancient civilizations out of practical necessities of daily life. The Greeks accepted these developments and added the more philosophical dimension (Aghadiuno, 1992).

In recent years, there has been an increase in publications that support integration of science and mathematics in school teaching and learning (for bibliographies see: Berlin, 1991; 1994). Particularly for grades K-8, the connections between the science and

mathematics curriculum are widely recognized and their integration is supported. This thesis is a response to existing curricular programs and a hope that integrated programs can provide a better response to problems of achievement and understanding.

In modern science teaching, as well as in mathematics, subject-specific objectives indicate skills and processes that the students should demonstrate on completion of their studies. Many of those skills and processes relate to both scientific inquiry and mathematical problem-solving (Neuman, 1993). Integration of science and mathematics enables students a more meaningful learning. "Mathematics provides a language for quantifying, measuring, comparing, identifying patterns, reasoning and communicating precisely." (Kleiman, 1991, p. 51). Mathematics, in turn, is better perceived while practiced in a real-life context (science) and not as unconnected, non-relevant information (McBride & Silverman, 1991). In an "ideal" integrated curriculum, subject matter boundaries are blurred and all science subjects are taught as one. At the same time, mathematics crosses all science subject areas either by being used as the language of science; as a tool for quantifying, measuring, and communicating; or in more theoretical forms as a way of thinking and developing models.

In contrast to the general agreement in theory about the benefits of integration of science and mathematics and about their natural connections, there is much diversity in practice. Integrated programs differ in their format. For example: "integrated science and mathematics" can be one activity that applies mathematical skills to science content or a mathematics lesson that uses problems drawn from scientific experiences (for examples see Berlin, [1991], *Instruction* section). It can also be an interdisciplinary unit

that connects science and mathematics subject matter and/or problem-solving skills and/or common concepts (e.g., Bray, 1969; Goodstein, 1983; Shann, 1977), or it can be a whole course or a program that is designed to teach both subjects as one identity (e.g., LaPorte & Sanders, 1993).

Furthermore, the way one perceives the integrated curriculum depends on one's primary point of view. Some scientists emphasize the role of mathematics as a primary language of science and a major analytical tool for technology (Kober, 1991) and would have mathematics principles embedded in science classes.

Mathematicians, on the other hand, see the sciences as the providers of interesting, relevant problems for teaching mathematical thought, as examples for mathematics applications. Some mathematicians see mathematics as pure and independent science, and believe it should be learned by itself to train students' minds to think. This point of view portrays science as the "study of the empirical world," the world we can feel with our senses (Aghadiuno, 1992), while mathematics is conceived as the world of ideas and theories. Mathematics can be taught independently from science, but the sciences can not be disconnected from mathematical language (Karpinski, 1929; Schaaf, 1965). Other mathematicians stress the applied aspect and claim that mathematics is a tool to help solve practical human problems in science and other fields. Building mathematical models to explain physical phenomena is part of science (e.g., Wilder, 1973). This calls for a "mathematization of science" (Aghadiuno, 1992; Southwell, 1994), a process that is influenced by the tradition of Newton, in which mathematics is a tool for physical

investigations and physics can correspond to areas of mathematical content and methodology.

> The raw data of physical existence, experience and experimentation are scarcely intelligible in themselves, and must therefore be dressed in some more suitable garb before the human mind can attribute proper significance to them. The formal procedures of mathematics have made a tremendous appeal to scientists as a medium ideally adapted to this purpose. (Aghadiuno, 1992, p. 688)

A different point of view expressed by some of the participants in the Wingspread conference as reported by Berlin & White (1992) calls for a complete assimilation of mathematical methods into science and scientific thought into mathematics. This approach is demonstrated by Neuman (1993) who identifies scientific skills as similar or identical to mathematical skills for a complete integration of science and mathematics instruction.

Another aspect of integration that has been extensively debated for many years is the relative share of each discipline in the integrated curriculum (e.g., Baker, 1975; Breslich, 1936; Flegg, 1974). This is less stressed in current integration literature because there is less concern today for content and rote knowledge and more emphasis on processes of learning. Because current reforms emphasize skills and concepts rather then content, several works list aspects (Berlin & White, 1994) or basic concepts and skills (Gallagher, 1979; Neuman, 1993) common to science and mathematics that can serve as a base for integrated programs. Consistent with Gallagher (1979), three broad skill areas can be generally defined as common to science and mathematics in school curriculum:

1. Ability to acquire information that includes reading text and comprehension of visual as well as verbal information.

2. Ability to interpret and manipulate information, to understand information in context, to predict and estimate future processing, and to be able to make connections with other data and processes.

3. Ability to use the acquired information that is learned in school, in problem-solving situations directly related to the material or transfer this ability to analogous situations.

A good, useful model for the integration of school science and mathematics needs to attend to a broad range of aspects in order to be effective. The Berlin-White Integrated Science and Mathematics (BWISM) Model (Berlin & White, 1994) includes an effort to sort the broad range of aspects that should be in an inclusive definition of science and mathematics integration. The model describes six aspects of science and mathematics integration:

> Ways of learning - integration can be based on how students experience, organize, and think about science and mathematics; derived from cognitive psychology and neuropsychology.
>
> Ways of knowing - integrated science and mathematics can provide opportunities to move back and forth between inductive and deductive ways of knowing.
>
> Process and thinking skills - integration can be viewed from the ways in which we collect and use information through investigation, experimentation, and problem solving.
>
> Content knowledge - integration of science and mathematics can be viewed from the perspective of the overlap of science and mathematics content.
>
> Attitudes and perceptions - integration of science and mathematics may be viewed from what children believe, how they feel about their involvement, and their confidence in their ability to do science and mathematics.
>
> Teaching strategies - instructional decisions related to time; cooperative work; use of laboratory instruments; use of technology (e.g., calculators and computers); and alternative assessments are often related to integrative science and mathematics experiences. (Berlin & White, 1994, pp. 3-4)

These aspects are suggested as a basis for characterization of science and mathematics

integrated resources, as guidelines for the development of new materials, and as operational definitions for research.

Other Features Associated with Integration

Cooperative learning.

One of the elements of new reforms in science and mathematics education is the use of cooperative learning in the classroom as a means to prepare students for social aspects of real-life. Integrated curriculum is often associated with cooperative learning. Group work seems to be suitable for the development of teams and projects to better achieve a holistic view.

In a cooperative learning environment, students work together to achieve certain goals, solve problems, and develop projects. There is a considerable amount of research that supports the values of cooperative learning as promoting understanding and cognitive development (Johnson, Johnson, & Johnson-Holubec, 1986). Several elements are necessary to ensure the success of cooperative learning: establishment of positive interdependence between learners, individual accountability, and proper use of social skills (Johnson et al., 1986).

Inquiry-based education.

Another teaching strategy that is recommended by current science and mathematics reforms is inquiry-based education. In this kind of learning students are "active investigators of the environment." (Wolfinger, 1994, p. 46) The notion of inquiry is

based on constructivists theories (Tobin & Tippins, 1993). The student is placed in a situation that enables free investigation, and thus the construction of individual, meaningful knowledge. By its nature, the emphasis of inquiry-based education is on problem-solving skills and analytical thinking (Wolfinger, 1994). The student is not directed by the teacher, but develops his own investigation while the teacher serves as a model or participant in the process. Inquiry-based education is said to promote creativity and concept development and allows students to construct their own knowledge in a more efficient manner (Roth, 1994; Roth & Bowen, 1994).

Problem solving.

Problem solving has been associated with science and mathematics instruction for almost a century (Helgeson, 1992). Problem solving can be described as a process by which the student learns to use rules and limitations to achieve a solution to a problem or a situation (Gagne, 1977).

Using inquiry-based instruction seems to enhance the problem solving ability of students (for a review, see Helgeson, 1992). In a meta analysis conducted by Curbelo (1984) it was found that problem solving can be taught effectively, and promote students' achievement, with any topic in science and math. The most effective method seemed to be inquiry (Curbelo, 1984). "The educator's task is to provide those opportunities that permit students to become proficient enough so that essential components in successful problem solving are brought to [a] level of atomicity." (Roth, 1991, pp. 640-641) Problem solving skills are not specific to mathematics or science. As it includes

"processes of interpreting data, controlling variables, defining operationally, and formulating hypotheses" (Helgeson, 1992, P. 2) it is naturally used in science and mathematics integrated curriculum.

Hands-on activities.

Another trend in science and mathematics reform is the recognition of the benefit of hands-on experiences (e.g., Thomson & Hartog, 1993; Wolfinger, 1994). The hands-on teaching strategy is recommended as a means for students to experience science concepts and processes first-hand and directly apply mathematical concepts. Influenced by constructivism, hands-on strategies are assumed to help students achieve understanding and acquire thinking skills (Blosser, 1994). It is also suggested that engagement in hands-on activities motivates students to continue learning and is a primary strategy to enhance learning, especially with young children (Wolfinger, 1994).

Higher-order thinking skills.

Schools today are expected to help students to develop higher-order thinking skills in order to enable students to take an active role in today's world (Resnick, 1987). The definition of higher-order skills is very broad and can include several domains: (a) from a philosophical point of view - critical thinking, reasoning skills, and logic (b) from a psychological point of view - it involves metacognition and cognitive strategies (Resnick, 1987). In the lack of exact definition Resnick (1987) lists several attributes that are considered to be part of higher-order thinking skills, among them: nonalgorithmic,

complex. yielding multiple solutions, involving application of multiple criteria, imposing meaning, and finding structure in apparent disorder.

CHAPTER III

SYNTHESIS

The integration of science and mathematics in school curricula is justified if it can help to provide even partial solutions to some of the current problems of science and mathematics education. A few of those problems were mentioned earlier: (a) low achievement and poor problem-solving skills; (b) lack of understanding, competence, and ability to apply school science and mathematics; (c) negative attitudes, low motivation, misconceptions, and science or mathematics anxiety of students; (d) irrelevance of school curriculum to actual real-life situations; and (e) an existing disparity between learning theory and actual instruction.

Current reforms in science and mathematics education have addressed the problems of education and have issued lists of outcomes suggested as the goals of science and mathematics education. The model suggested for science and mathematics integration is an outcome-based model. Therefore, the first stage when conceiving an integrated program should be to define the desired outcomes common to science and mathematics education. Desired outcomes of science education have much in common with mathematics education outcomes. As the aim of integrated curriculum is to improve

learning of both science and mathematics, integration should concentrate on those common features, meeting points that can be easily defined.

Outcomes should be identified based on reform efforts, a recognition of current problems, and the possibility of reaching desired solutions through science and mathematics integration. Research and experience can help determine the best means to influence the outcomes. Unfortunately, because there are not enough data from science and mathematics integration research, there is a need to import knowledge about learning from constructivism and cognitivist theories.

Integration of science and mathematics should be designed and performed in the most efficient manner to accomplish valuable outcomes in all domains. This means that science and mathematics integration across the curriculum should incorporate "good" pedagogy. In fact, integration is very often associated with elements of current pedagogical trends, e.g., cooperative learning, inquiry-based instruction, and hands-on activities. This makes it difficult to isolate the impact of integration from the broader scope in current reforms.

In this chapter, a synthesis of the desired and actual outcomes in science and mathematics integrated curriculum together with relevant knowledge from learning theories and research and some pedagogical aspects is presented. This synthesis is expected to detect the supportive evidence for integration as well as the omissions that will generate the fundamental issues and the research agenda to be addressed in the future.

Summary of Main Findings

The review of the literature revealed several issues related to science and mathematics integration. Some of these issues appear to overlap and have common features that connect the different perspectives from learning theories and pedagogy.

The desired outcomes and goals common to science and mathematics education were grouped together in relation to specific characteristics of science and mathematics integration. Other aspects of "good" instruction that are associated with science and math integration, as portrayed by current trends in current pedagogy such as: constructivism, developmentally related aspects, cooperative learning, inquiry-based instruction, hands-on activities etc. were excluded. Although these aspects are relevant to science and mathematics integration, and sometimes embedded in the integration literature, they are not to be considered as characteristics of integration. Correlations between desired outcomes and the elements of integration help identify the outcomes that are particularly relevant to science and mathematics integration in school curricula.

Many of the desired outcomes that are specified in reform documents have direct relevance to the integration of science and mathematics across the curriculum. Features of science and math integration were first correlated with desired outcomes, then an attempt was made to determine the supportive evidence for each based on research and evaluation literature on science and mathematics integration. Because there is insufficient research which directly relates to science and mathematics integration, the synthesis incorporates elements of learning theory. The combination will enable the determination of "weak" points that need further research.

Table 1 presents a summary of the synthesis process. The attributes of science and mathematics integration were grouped according to their relation to desired outcomes that were described in chapter II. The same attributes were matched to related research and experiential findings from the area of science and math integration and to elements of learning theories. All the details for the table were collected from the literature base chapter. The decisions concerning the position of each feature within Table 1 are subjective. The intent was to couple each science and mathematics integration attribute with an appropriate element of the desired outcomes and match these to research, experience, and learning theory. Some features may appear in more than one position, for example, when an integration attribute seems to be related to two different desired outcomes.

A cursory look at table 1 reveals several empty cells, mostly in the research and experience domain. This exposes the main problem that emerges from the synthesis. Research on many aspects of science and mathematics integration is inadequate, partial, or absent. Therefore, an outcome-based model has to be established, to some extent, on assumptions and recommendations. Nevertheless, some actual support for integration can be drawn from research and learning theories.

Table 1

Summary of the synthesis of science and mathematics integration with aspects of learning theories in light of desired outcomes.

Elements of Sci/Math Integration		Elements of Learning Theory
Attributes	**Research & Experience**	
Desired Outcome: Science and mathematics for all.		
More opportunities, different aspects presented.	*All* students seem to show greater interest.	
Desired Outcome: Knowledge and understanding of basic concepts and processes.		
Knowledge domain: emphasis on integrated concepts & overlapping principles. Multimodality. Stresses process skills, not content.	In most cases, no preference or disadvantage for integrated curriculum in achievement tests. A significant improvement in math and science process skills was reported for students in the TIMS program. Elementary school students performed better on the conservation and transitivity tasks.	Information connected to prior knowledge is remembered better. Brain records associations. Memory retrieval promoted by: previous experience, appropriate "priming." Synaptic connections are a function of experience. Multimodal stimuli enhance memory and understanding.
Desired Outcome: Prepare for real-world situations.		
Reflects real-life situations, no artificial separation by subjects. Present broad range, related information.		Knowledge should be meaningful & relevant. Memory "makes sense" in context. Memory favors connected, holistic stimuli. Retrieval by mechanism of priming.
Desired Outcome: Use of science and mathematics, communication competence.		
Math to quantify science & science utilizes mathematical models. Communication domain: math used as the language of science, use of graphs.	Elementary school students' ability to use conservation reasoning was enhanced with science experience. 8th graders chose to use more mathematical representations.	Piaget: language skills; ability for analysis and reflection are developmentally related. Experience helps in development.

Table 1 (continued)

Elements of Sci/Math Integration		Elements of Learning Theory
Attributes	**Research & Experience**	
Desired Outcome: Develop holistic views/thinking, understand connections, see patterns and relations.		
Holistic presentation, all aspects included, connections pointed out, subject boundaries are blurred.		Brain searches for common patterns and connections; parallel processing; memorization favors wholes.
Desired Outcome: Ability to apply and transfer knowledge.		
Analogies are demonstrated. Students encouraged to apply common concepts and skills. Students are guided to transfer.		Memory/creation of synaptic connections is a function of input and experience.
Desired Outcome: See, understand, and value place of science/mathematics in society.		
Uses real-world situations. Demonstrates math/science in context. Presents a realistic picture.		Relevant, "in context" information, is better remembered and retrieved.
Desired Outcome: Develop positive attitudes, motivation, confidence in self ability to do science/mathematics.		
Makes school science and math more appealing, interesting & relevant to students. Personalizes learning, more flexibility in curriculum.	Significant increase in positive attitudes of some students. Enthusiasm & satisfaction are also reported.	Knowledge should be meaningful and relevant to the individual in order to be learned, remembered and retrieved. Attention (and thus-reception) is better when stimuli is meaningful & relevant.

The following are explanations of the synthesis as summarized in table 1:

1. The new vision of schools includes education for all students. In relevance to science and mathematics education, it means enabling all students access to the acquisition of basic mathematical and scientific skills and understandings. This constitutes the scientific literacy and self-confidence that brings students to a minimal level of knowledge that will enable them to become effective members of society. Integration of science and mathematics across the curriculum offers a suitable strategy for promoting these goals. Integrated science and mathematics curriculum adds many different aspects that can appeal to a diversity of students, and thus to constitute a proper response to the notion of "science for all." Yet actual support for this notion is mostly circumstantial. There is some evidence that all students show greater interest in science and mathematics in an integrated curriculum (see Attitudes section of chapter II).

There is hope then that an integrated science and mathematics curriculum would provide more students access to these subjects. More research is required in this domain to establish the validity of integrated programs as an effective means to reach a variety of students.

2. Current trends in curriculum development for science and mathematics stress the need for change in focus. Instead of teaching more content, understanding of basic concepts and acquisition of process skills are given greater prominence. One of the characteristics of integrated science and mathematics curriculum is the emphasis on connections between disciplines based on overlapping concepts and process skills.

Integrated curriculum allows various possibilities for teaching that emphasizes concepts and process skills common to science and mathematics.

A strong support for teaching a more holistic view of scientific and mathematical concepts and skills comes from learning theories. From brain research, it is apparent that meaningful learning that leads to understanding is more successful when stimuli are presented within a well defined context, that presents a holistic view, and is in accordance with previous learning and existing memory.

Research has not shown a definite advantage for integrated curriculum in terms of achievement. In fact, not many studies have investigated this issue. From the few studies that have tested achievement and the understanding of students who experienced integrated programs compared to those who studied in a traditional manner, it appears that in most cases integration does not effect the achievement level of the students. In some studies, a positive affect is reported for certain students (above average students: Friend, 1985), or the entire sample (of elementary students - Goldberg & Wagreich, 1991). Nevertheless, it is not completely clear whether the better achievement is to be attributed directly to the integration of science and mathematics in the curriculum or is also due to the use of modern "good" instructional strategies in the integrated program. The research in this area is still not adequate to determine a benefit or disadvantage for integrated curriculum.

3. A major concern of recent views of teaching is the development of problem-solving and reasoning skills and an ability for rational thinking, qualities that are important for all fields of study as well as in real-world endeavors. Most science and

mathematics integrated curricula emphasize these elements. There is evidence from research on integrated curriculum that suggests an acceleration of some cognitive development with integrated instruction (For a partial review see: Koballa & Bethel, 1984). This is consistent with views from cognitive theory that mental/cognitive growth depends on the organization of experiences (including individual experiences and social interactions) into a more holistic logical system (e.g., Loomis & Prickett, 1985; Wheatley, 1991). This process is internal to the learner, but can be promoted with appropriate external stimuli and experiences. More research on the direct influence of integrated curriculum on the development of higher-order thinking skills is needed in order to determine the specific contributions of science and mathematics integration to cognitive growth.

4. Another interest of current reforms is preparing students for the real world. This includes the ability to use and apply science and mathematics in real-life situations, to understand and value the place of science and mathematics in society, and to know and appreciate the role of technology and the relations of science and mathematics to new developments. Part of the preparation of students for these real-life experiences is exposing them to the functions of science and mathematics in everyday life and guiding them in acquiring the necessary skills to enable them to use, manipulate, and communicate scientific and mathematical concepts.

Integration of science and mathematics across the curriculum is a direct consequence of the place of science and mathematics in society and in real-life. Integrated curriculum enables the presentation of holistic reality. It also enables one to relate science,

technology, and society and to place mathematics as the language of science as well as a science in its own right with applications in all other disciplines.

The review of research on integrated curriculum did not reveal any follow-up study that in fact searched the relations between integrated science and mathematics curriculum and actual functioning of students in the real world during and after their "school years." Some inferences can be made however; research showed that 8th graders who participated in an inquiry-based integrated program chose to use mathematical representations increasingly with time (Roth & Bowen, 1984). This may have implications for possible influences of integrated programs on students' behavior. It seems that students that are engaged in inquiry-based integration activities are encouraged to apply mathematical tools to communicate scientific ideas. Hopefully, this behavior may be carried on to real-life situations. There is a problem though in isolating the influence of integration in the research studies from the influence of the teaching strategies like hands-on and inquiry.

From learning theories, it is apparent that in order to enable students to learn, understand, and be able to apply scientific and mathematical knowledge, it should be presented in context. Only then can appropriate retrieval from memory be achieved by a mechanism of priming (Squire, 1986). If the aim is to prepare students for real-life situations, then science and mathematics have to be presented in that context, i.e., should be relevant to everyday life experience, connected to applications (like technology), and provide the students with manipulative opportunities related to real-world problems. Then, when students encounter actual real-world situations, appropriate recall would be

achieved with the accessibility to stored "chunks" of knowledge through priming by related stimuli (e.g., Caine & Caine, 1991b; Domasio & Domasio, 1992).

5. Part of the recognition of the role of science and mathematics in the real world is to develop a holistic view of science and mathematics. This should help students to see general patterns and understand the connections and relations within phenomena, theories, and consequences. Realization of such connections may help to promote the ability to transfer knowledge and skills across the disciplines and between situations. Learning theories suggest that the brain seeks holistic patterns and that knowledge is developed as a whole and can be applied most efficiently in the same manner it was acquired (e.g., Caine & Caine, 1991a). The relations among stimuli are recorded in the brain in neural networks as a function of the actual learning experience (Anderson, 1992; Kandel & Hawkins, 1992). Thus, if students are presented with holistic ideas, with emphasis on connections and common processes and concepts, they are more able to apply science and mathematics in different situations and relate them to the whole.

6. One of the main problems of science and mathematics education in the United States is that a significant percent of students reject science and mathematics in the early stages of their learning experience. Those students either resent science and mathematics or try to avoid it because of anxiety, lack of motivation, or feelings of irrelevance to their lives. The first aim of science and mathematics education reform is therefore to evoke students' interest in these fields. Integrated curriculum can help reach those goals. Science and mathematics integrated curriculum by its nature, is usually more flexible in content and procedures and enables teachers to demonstrate uses of science and

mathematics in technology and other aspects of society. For example, by working on themes or projects, students may be engaged in scientific and mathematical processes in indirect ways that diminish effects of anxiety and negative attitudes. In fact, there is evidence that science and mathematics integrated curriculum does increase the development of positive attitudes of students toward school science and mathematics and its implications to the real world. Publications that describe integrated instruction (Berlin bibliographies, 1991, 1994) usually report positive reactions of students. This is also supported by research and evaluation of integrated programs and coincides with claims of learning theories that reception and attention are better when the stimuli are relevant and meaningful. Nevertheless, it is difficult to identify what is the actual share of integration in the development of more positive attitudes toward science and mathematics. Integration is often accompanied by teaching strategies recommended as "good instruction" by current pedagogical theory. More research is required in order to isolate the effect of science and mathematics integrated curriculum. This should probably be done by comparing students attitudes during "good instruction" with and without science and mathematics integration.

CHAPTER IV

SUMMARY

The synthesis of science and mathematics integration literature with other domains of science and mathematics education and the different perception of learning processes, generates a framework for the development of an outcome-based theoretical model. In general, it seems that the different perceptions advocate the trend toward integration of science and mathematics across school curricula. Although there is only little direct evidence from research to support such integration, there are no reports of drawbacks from the learners' perspective, and no direct findings to strongly contradict the notion that students can benefit from integrated studies.

Toward a Model of Science and Mathematics Curriculum Integration

In setting the grounds for the development of an outcomes-based model for the integration of science and mathematics some factors were contemplated: (a) science and mathematics pedagogy relevant to integration including theory and instructional strategies; (b) relevant knowledge from cognitive and developmental psychology; and (c)

learning theory derived from brain research. Desired and actual outcomes, and recommendations were identified.

Science and mathematics integration is considered to be one possible strategy for reaching desired outcomes in education. In Figure 1, "integration" is placed in the middle because it is central to the theme of this document. The connections between integration and the other domains are the key for successful integration. In Figure 1, strong relationships that include: recommendations, influence, and feedback are marked with thick bold lines. The finer the lines are, the weaker the links represented. For example, the link between actual outcomes and integration theory (and action) is very weak. This is because of insufficient research and evaluation of science and mathematics integration across school curriculum. It seems that an actual path leads from learning theories to pedagogy, i.e., actual pedagogy strategies draw from constructivism and Piagetian theories that originate directly from learning theories.

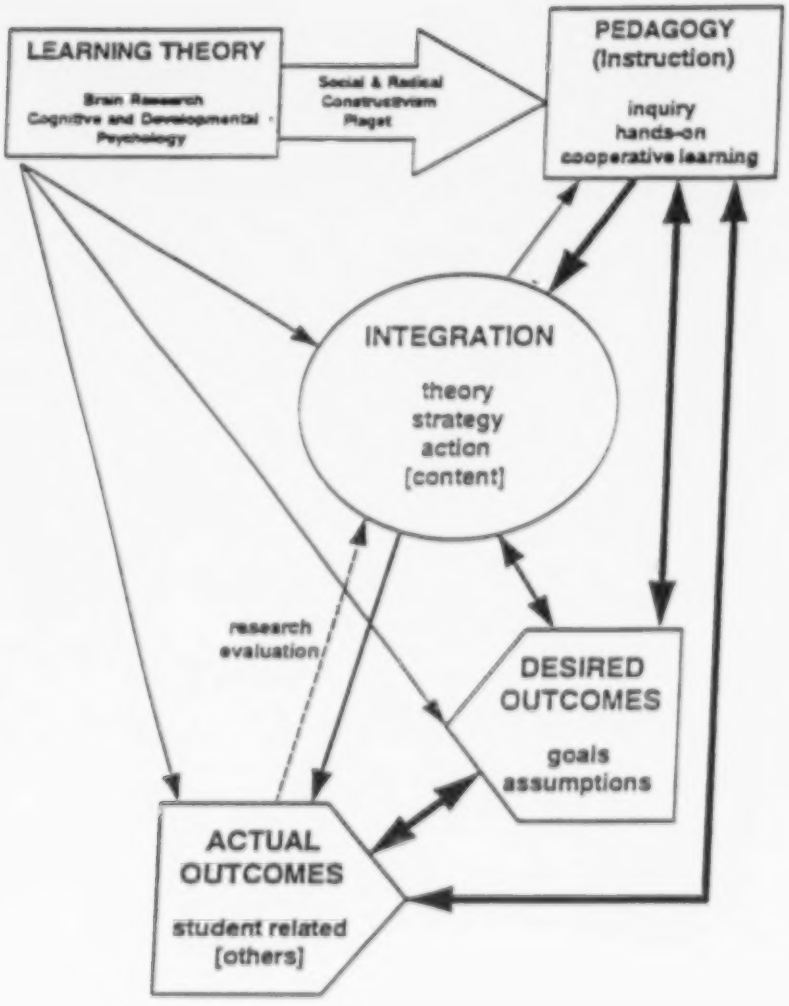

Figure 1. A synthesized approach to science and mathematics integration across the curriculum: A model of its relations to other perspectives on learning.

Figure 1 demonstrates the relations of the notion of science and mathematics integration to the other perspectives. It seems that integration theory as well as practice are not isolated from general pedagogy or learning theory and is also related to the goals of education as apparent in the reciprocal relations between science and mathematics integration and desired outcomes. Learning theories actually have only remote influence on integration although a support for integration can be found in both learning theories derived from brain research as well as from cognitive psychology. It seems that the stronger actual relations exist between pedagogy and integration. In a way, integration of science and mathematics can be considered as part of general pedagogy. As expected, desired outcomes are strongly connected to pedagogy and to actual outcomes as well.

The synthesis of science and mathematics integration with other perspectives, in relation to desired outcomes and goals of education today, leads to the development of the following stages constituting a basis of an outcomes-based model of science and mathematics integration in school curriculum. The model is based on the procedures needed to produce this document, and represents only suggested outlines for the establishment of an effective science and mathematics integration curriculum.

Stage 1: Determine Relevant Outcomes

The first stage toward successful science and mathematics integration is to determine desired outcomes and goals. Educational reforms are directed at an overall change in student outcomes, an improvement of achievement, process skills, and attitudes. The main desired outcomes that were identified in this work are grouped below:

1. science and mathematics for all.

2. development of student problem-solving skills, active and rational thinking, reasoning skills, and creativity.

3. student achievement of a satisfactory level of knowledge and understanding of basic concepts and processes common to science and mathematics.

4. student readiness for the real world: ability to transfer, manipulate, and communicate science and mathematics knowledge and process skills.

5. student development of holistic views, recognition of patterns, connections, and relations in the real world.

6. student understanding of the place of science and mathematics in society.

7. student development of positive attitudes toward science and mathematics, motivation, and self confidence.

Stage 2: Identify Integration Attributes

In the second stage, the characteristics of integration that seem to comply with the goals were identified. Acceptance of these features as adequate responses to desired outcomes and goals need to be substantiated by findings from the research on science and mathematics integration. Data from research is insufficient or lacking, hence it is necessary to infer what integration may mean to students on the basis of additional attributes from learning theories. The following were identified as the main characteristics of outcome-based science and mathematics integration:

1. Accessibility to all students and personalized learning possibilities. Support comes from integration literature and mostly based on intuition without sufficient research results.

2. Emphasis on integrated process skills and concepts and not just knowledge acquisition. This is in accordance with learning theories derived from brain research that emphasis the need for connections and relations between stimuli in order to achieve actual understanding.

3. Instructional strategies include hands-on activities, inquiry, and cooperative work. Multidisciplinary materials should be varied, relevant, and holistic and represent real-world situations. These features seem to be important for the promotion of effective, meaningful, life-long learning according to current pedagogy, attributes of learning theories, and some findings from research on integration.

Stage 3: Applications and Research Agenda

On the basis of desired and actual outcomes, recommendations for actions can be offered. These include direct applications for the implementation of science and mathematics integrated curriculum and suggestions for further research to "fill in" insufficient support in some domains.

It seems that integrated curriculum cannot be separated from "good instruction." For the implementation of integrated curriculum, educators need to be concerned with the recommendations of current pedagogy and learning theories: (a) experience should be relevant, meaningful, and related to holistic systems of the real world as well as to past

knowledge and conceptions; (b) presentation should be appealing to all students, varied in stimuli and action, and appropriate to developmental stages; (c) a constructivist approach should be adopted with inquiry-based learning and hands-on activities; (d) for the social mechanism of learning and knowing to be addressed, cooperative work is recommended; and (e) the learning environment should be pleasant and non-stressful.

Integration of science and mathematics across the curriculum needs to be examined in relation to desired outcomes and be related to theoretical benefits as suggested by learning theories. Several attributes of learning theories specifically support integration. These are related to learning and memory acquisition (e.g., neural networks, parallel processing), retrieval from memory (e.g., priming), and use of knowledge (e.g., transfer).

The research agenda for the near future needs to include most areas of science and mathematics integration. It seems that the strongest support for integration currently comes from the attitude domain. Research still needs to address the following issues: (a) Is integration of science and mathematics an appropriate response to achieve desired outcomes of current educational reforms? What are the actual contributions of integration? (b) Does an emphasis on process skills and common concepts promote student achievement in science and in mathematics? (c) Is cognitive development facilitated by features of integrated curriculum? What are the most effective features, and how do they influence the development of higher-order skills? (d) What are the effects of the integration of science and mathematics on different groups of students (e.g., minorities, 'at-risk' populations and low/high achievers)? (e) Does the integration of

science and mathematics influence the future life of students? Do they tend to chose more science/mathematics related careers? Do they demonstrate scientific literacy and better mathematics competence?

Conclusion

There is a clear need for more research on integration of science and mathematics in school curricula, despite strong rationale in general for the integration of the curriculum. The aspects of research to be emphasized in the near future stem from the desired outcomes of science and mathematics education. These are determined in several domains: (a) knowledge acquisition and concept understanding; (b) development of process skills; (c) ability to communicate and apply science and mathematics; (d) realization of connections and development of holistic views; (e) development of scientific literacy and mathematical competence that would enable active participation in decision making for the benefit of society and self; and (f) development of positive attitudes toward science and mathematics in school and in general.

Actual support either from research on science and mathematics integration or from the other perspectives that were presented in this work (learning theories derived from brain research and cognitive psychology) is sometimes provided but mostly it is inadequate or missing. Educators should be aware of these omissions and advocate or undertake further research in these domains.

Many integrated programs and activities are currently operated in schools. It is highly recommended that aspects of research and evaluation be added to these programs.

Teachers who implement integrated programs should join the research efforts and inquire into the issues of integration that were specified above. In the future, in designing integrated curricula all aspects must be considered to create effective science and mathematics integrated curriculum programs for successful education.

APPENDIX

LIST OF RELEVANT JOURNALS

American Biology Teacher, The
American Mathematical Monthly, The
American Journal of Physics
Arithmetic Teacher
British Journal of Educational Technology
Children's Literature in Education
Classroom Computer Learning (now: Technology & learning)
Curriculum Review
Developmental Psychobiology
Developmental Psychology
Education in Chemistry
Educational Technology
Educational Technology Research and Development
Educational Science
Educational and Psychological Measurements
Educational Technology
Educational and Training Technology International
Educational Studies in Mathematics
Elementary School Journal
European Journal of Science Education, The
Instructional Science
Instructor (formerly: Grade Teacher; NOW: Teacher + Instructor)
Integrated Education (now: Equity and Excellence)
International Journal of Mathematical Education in Science and Technology
JCT - An Interdisciplinary Journal of Curriculum Studies
Journal for Research in Mathematics Education
Journal of Biocommunication
Journal of Biological Education
Journal of College Science Teaching

Journal of Computers in Mathematics and Science Teaching
Journal of Educational Psychology
Journal of Elementary Science Education
Journal of Experimental Education
Journal of Research in Science Teaching, The
Journal of Teaching and Learning
Journal of Vocational and Technical Education
Learning
Learning and Instruction
Mathematics and Computer Education
Mathematics Teacher (formerly: Mathematics Student Journal)
Mathematics Teaching
Mathematics in School
Micro Math
Phi-Delta Kappan
Physics Teacher, The
Physics Education
Quarterly American Education Research Journal
School Science Review
School Science and Mathematics
Science
Science Activities
Science and Children
Science Education
Science Teacher, The
Science Scope
Studies in Higher Education
Studies in Mathematics Education
T.H.E. - Technological Horizons in Education
Teacher (formerly: Grade Teacher; NOW: Teacher + Instructor)
Technology & Learning (formerly: Classroom Computer Learning)
Technology Teacher, The
Vocational Education Journal
Young Children

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